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Off-grid approach to support the small scale food producers in rural areas

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Abstract

This paper concerns a study of compact system designed to ensure energy independence of buildings located in rural areas: the Off-Grid Box - OGB. This system is an integrated device, self-contained in a container, which provides and producers essential service and resources namely, electricity, hot water, clean water for washing and irrigation and a water purification process that pasteurized/distilled wastewater. The goal of study is to experiment the adoption in agriculture of technology solutions able to satisfy the energy needs (in terms of electricity) of small scale food producers in rural areas with high environmental and landscape value and to identify a compact modular system dedicated to family farming to reduce external inputs and waste. The specific objective is to find a winning solution for self-sufficiency (in off-grid vision) and reducing emissions of the small scale family farms, useful for the sedentary, semi-sedentary and mobile production and processing units. This study is focused on the potential of OGB to guarantee the energy needs of small slaughterhouses in a rural area of Umbria Region. These scenarios are interesting for small family farms that adopt sustainable models and methods of production with low environmental impact and low energy demand to define the indications for their winning energy planning.

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Keywords: renewable energy , natural resources, off grid system, rural development, off-grid farming

1. Introduction

The energy planning and rationalizing the use of energy are strategic issues in this historical moment. The European Union has set itself the goal of achieving by 2020 the coverage of 20% of energy needs from renewable

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sources and, compared to 1990, the 20% reduction in emissions of greenhouse gases and increasing the 20% energy efficiency, (European Commission COM 2020, 2010). At european level the debate is open and political activity is ongoing (European Commission COM 130, 2014).

1.1. Rural areas and Energy Sovereignty

In the European strategy 2014-2020, the rural areas are involved in specific integrated projects aimed to the development and enhancement of local communities (European Commission Partnership Agreement for Italy, 2014; European Commission COM 8021, 2014). Rural areas are considered strategically relevant to foster a more sustainable and inclusive national growth, for this reason is strategic the negotiation that currently the Italian regions are conducting at European level on European Agricultural Fund for Rural Development (EAFRD).

Generally these areas are characterized by low power consumption (in relation to urban zones), which, however, are struggling to be satisfied. In these contexts it is particularly important the concept of energy sovereignty: the right of people to have access to energy and to make their own decisions over sustainable energy sources and sustainable consumption patterns. The concept of energy sovereignty is a part of the interesting alternative vision of the green economy, and is based on development models, accepted by local communities, focused on the sustainable and common use of natural resources (UN-NGLS, 2013; La Via Campesina, 2013). This concept recognises energy as a human right. It also seek to return the control of energy users, rather than remote corporations that seek to profit from regardless of its impact on consumers or how it is generated (World Development Movement, 2014; Menges, 2003). Energy sovereignty is strongly linked to the development of renewable energy. In Italy the increase in the use of renewable energy reflects the European trend (Tab. 1).

Tab 1. Installed capacity and gross production in Italy 2008-2012 (Data source: Terna, and estimate 2012 GSE).

Gross efficient power (GW)	2008	2009	2010	2011	2012	Percentage increase
Hydraulics	17,62	17,72	17,88	18,09	18,20	3%
Aeolian	3,54	4,90	5,81	6,94	7,97	56%
Solar	0,43	1,14	3,47	12,77	16,35	97%
Geothermal	0,71	0,74	0,77	0,77	0,77	8%
Bioenergy	1,56	2,02	2,35	2,83	3,80	59%
Total renewable	23,86	26,52	30,28	41,40	47,09	49%
Thermoelectric (includes all fossil fuels)	76,73	78,67	79,11	79,71	na	na
TOTAL	100,59	105,19	109,39	121,11	na	na
Gross electricity (GWh)	2008	2009	2010	2011	2012	Percentage increase
Hydraulics	47,20	53,40	54,41	47,80	41,90	-13%
Aeolian	4,90	6,50	9,13	9,90	13,90	65%
Solar	0,20	0,70	1,91	10,80	18,80	99%
Geothermal	5,50	5,30	5,38	5,70	5,60	2%
Bioenergy	6,00	7,60	9,44	10,80	12,30	51%
Total renewable	63,80	73,50	80,27	85,00	92,50	31%
Thermoelectric (includes all fossil fuels)	253,80	219,00	221,81	217,70	204,80	-24%
TOTAL	317,60	292,50	302,08	302,70	297,30	-7%

This deployment of renewable energy has led to problems with the existing energy distribution networks (such as overloads), which should be designed again with energy storage systems at local level (Delfanti and Olivieri, 2013).

It is clear the importance of thinking in terms of energy sovereignty, imagining an energy system capillary, free from the presence of the classic distribution networks. The research is moving towards the integration of the various energy sources to design off-grid systems adapted to the territories and the needs of local communities (Brinkhaus et al., 2011; Suha Yazici et al., 2013; Bielmann et al., 2011; Gray et al., 2011).

1.2. Rural areas and small scale food producers

The study area examined by the present study is the Valnerina (Umbria), very interesting rural area in terms of landscape and environment characterized by a marked resilience of small family farms that practice sheep farm. Nationally the sheep farm is a strategic sector, as Italy is among the top 5 producers of sheep's cheese in the world (Faostat, 2011). In Umbria region specifically there are 1,475 farms for a total of 107,126 head of sheep (Istat, 2010). In this framework, the small family farms are the activities most affected by the crisis and that need of services in support of production. In this direction it is strategic for example consider establishing mobile slaughterhouses to serve the small and very small sheep farms (Umbria Regional Livestock Plan, 2014).

1.3. Energy storage systems

In Italy renewable energy sources are divided into programmable and non-programmable. The first category includes the production units in the reservoir and hydroelectric basin, municipal solid waste, biomass, units using fossil fuels, fuels process or residues; while the second category includes hydroelectric production flowing, wind, geothermal, photovoltaic (PV), biomass and biogas (Italian Authority for Electricity Gas and Water, 2009). For renewable energy sources non-programmable the aim is to obtain energy autonomy through the best energy storage systems that can guarantee different profiles of energy demand. In Italy the PV system is the renewable energy source more developed in recent years thanks to the incentive policy implemented at government level (Fig. 1), at the moment the debate is open to the regulation in the use of energy storage systems in new plants and for introducing them to existing plants (Italian Authority for Electricity Gas and Water, 2013).

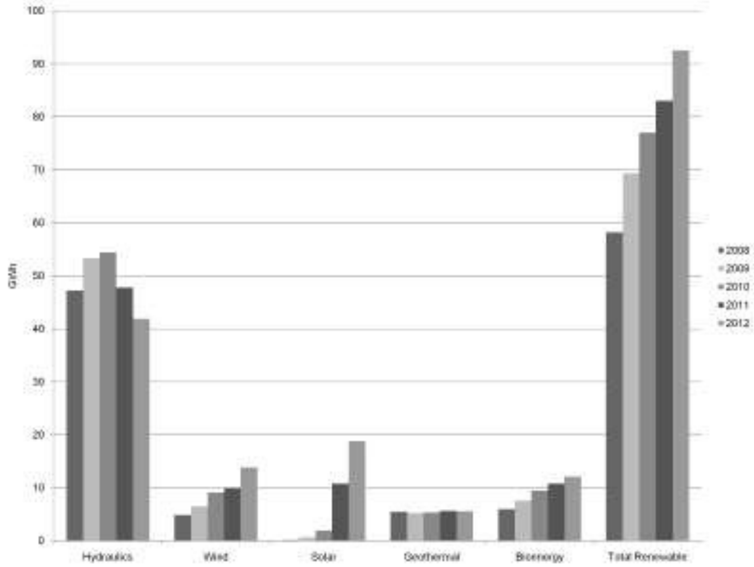

Fig. 1 - Gross Electricity Production in Italy (GWh), 2008-2012 (Data source: Terna, and estimate 2012 GSE)

Research is focusing currently on the analysis of the technical and economic feasibility of smart grids, in order to assess the optimal organization and their effectiveness in a context of energy sovereignty (Moseley and Garche, 2014; Thompson and Duggirala, 2009; Chaurey and Kandpal, 2010; Kanase-Patil et al., 2010). In this framework often the researches are focused on finding optimal energy carriers and the integration of renewable energy sources. The electricity storage systems are classified according to the technology used in electrical (super-capacitor, superconductive magnetic coil), mechanical (pumped hydro power, compressed air energy storage system, flywheels), thermal (themoelectric storage) and chemical (lithium-ion battery, lead-acid battery, high temperature batteries, flow batteries, hydrogen storage, natural gas storage system (Moseley and Garche, 2014; Linden and Reddy, 2002). In this work are compared Valve-Regulated Lead-Acid Battery type gel cells (VRLA) and Lithium-Ion battery (Li-Ion), as they represent the energy storage systems widespread in the market and potentially suitable for applications in a small plants for their costs content than the fuel cell (energy carriers potentially more efficient). The VRLA battery have as much advantage of their low cost: a battery (eg. 70 Ah) is relatively inexpensive when compared to the other with the same operating principle chemical, other positive aspects are their long life and reliability even at low temperatures. The negative aspects are low energy intensity, losses due to mechanical stress, the phenomenon of sulfation, high weight, lead toxicity (Linden and Reddy, 2002; Salkind et al., 2014). The Li-Ion battery offers a very high energy density (7 grams of metal produce up to one mole of electrons) and have no memory effect. On the negative side there are the high costs, the flammability of the solvent, the marked unsustainability of the production chain of lithium (Linden and Reddy, 2002; Ehrlich, 2014). The various storage technologies have a different prospects for development in the next future. The main challenge is to assess the scalability and integration of the various renewable energy sources non-programmable and the various storage systems.

1.4. Off-Grid Box

The Off Grid Box – OGB, (designed and developed by La Fabbrica del Sole - FdS - www.lafabbricadelsole.it, an Italian group of several organizations) represented in Fig. 2, is an integrated technical device, self-contained in a 6 feet container, which provides and produce – with a simple Plug&Play concept – essential services and resources namely, electricity, hot water, clean water for washing and/or irrigation and water purification process harvesting and storage for washing or irrigation and a water purification process that pasteurize/distils waste water. The unit (OGB) has an inclined photovoltaic (PV) array on its roof that produce electricity and harvest rain water by means of an eave with a coarse filter. This way can also be used to introduce clean water from any other source inside the OGB. Water is stored in a 1500 liters tank housed inside the unit. The captured rain water, after passing through a very fine filter process, is automatically filtered and depurated using a UV-Lamp. The same captured rain water will in addition, refill the inner liquid inside the solar water heater. The solar water heater is an indoor stainless steel tank which contains around 200 litres of liquid (simplewater or anti-freezing water or salt or contaminated water, etc...) heated by 20 vacuum glass tubes placed outside the unit facing the South side and also powered by an electric backup. On the same side, the outlet connection for the heat exchanger is installed that can instantaneously warm up water that flows through it and through the outlet of the clean water. The photovoltaic roof is composed of six, or more, 250 Wp mono-crystalline solar modules connected in parallel to a control panel with fuse protection (and spares) for safety standards. The panels are connected to a charge controller to charge the batteries whilst preventing the batteries from deep discharge or other potential damages. A solar inverter is connected to the batteries providing a standard (AC 110V or 220V at 60-50Hz) alternate current which can be taken from a plug affixed next to it and which is directly wired to the building, ready to plug any device on a multi-outlet at the other end of the wire. The same inverter can transform the energy from a wind turbine, usually a 500W one, attached at the OGB structure. The batteries and the electric components are mounted on the wall opposite the water system in order to protect them from possible water leaks or splashes. Below the batteries, additional storage space is also available for extra components which may be requested to be installed, such as large pumps, a hydrogen electrolyser, UV water filter, wind turbine accessories, and more. In view of the above, the Off Grid BoxTM can be provide you with: a) the required electricity from the photovoltaic system; b) clean water from rain collection or other local sources (well, creek, etc..) and water pasteurization and distillation of contaminated and/or dirty water; c) the necessary hot water from the solar water heater; d) the possibility of adding extras such as hydrogen electrolyser, storage and burner for cooking, wood/pellet stove, high powered pressure pumps, additional water filters as reverse osmosis for desalinization, a small scale wind turbine, and more.

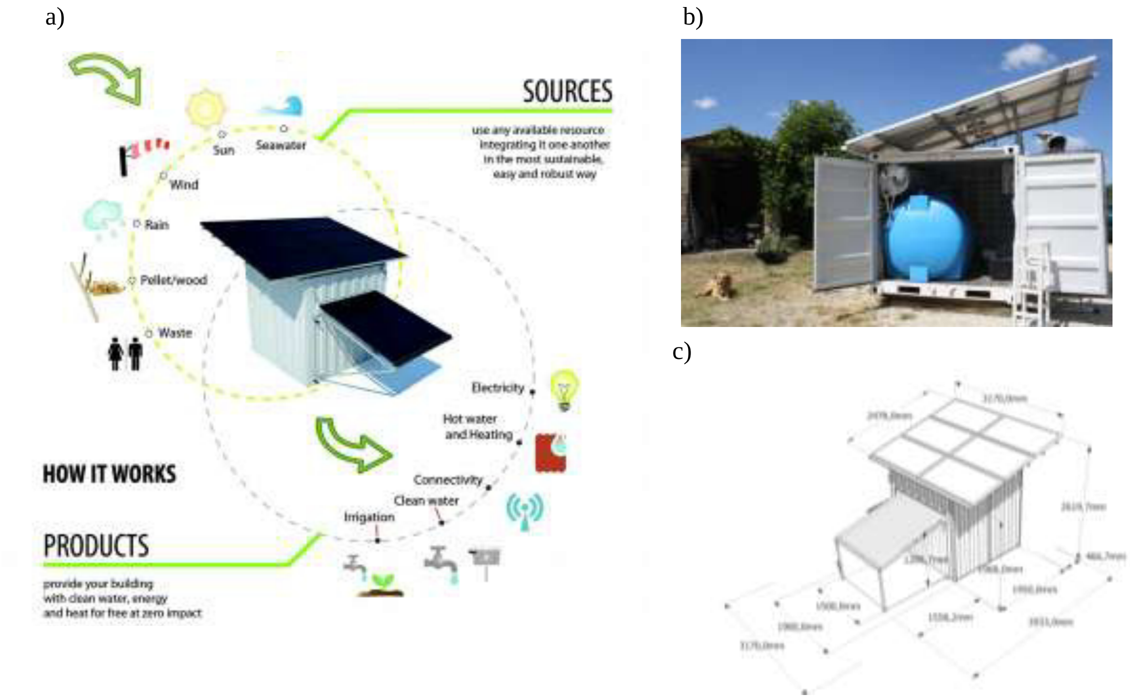

Fig. 2 – a) OGB scheme: technologies mix; b) OGB installation example; c) OGB dimension after complete installation

The case study for present work is one of the first installations made with an OGB located in central Italy (Tuscany - Pieve San Giovanni, Arezzo province). The OGB was installed in May 2012, the container was placed basement near the building, and the PV panels have been placed with integrated coverage on the roof of rural house (Fig.3). In this case the system, using the incentives, was connected to the grid in order to maximize the economic investment with the selling of the energy surplus. In this work, between different technologies contained in the box (PV, heat, rain water collection and water treatment), it is considered the only component of the solar system. The PV installed covers an area of 19.502 m2 and develops 2.88 kW. Its consists of monocrystalline panels 12, placed in series, characterized by a power of 230 wp of the size of 992 * 1640 mm. The objective of the work consists in evaluating, for the OGB, the potential of energy production of the PV system with different energy storage system, in order to meet the energy needs of small family farms in rural areas. In the case study in terms of energy the levels of production and consumption are related to the needs of a rural house with two people and a small garden.

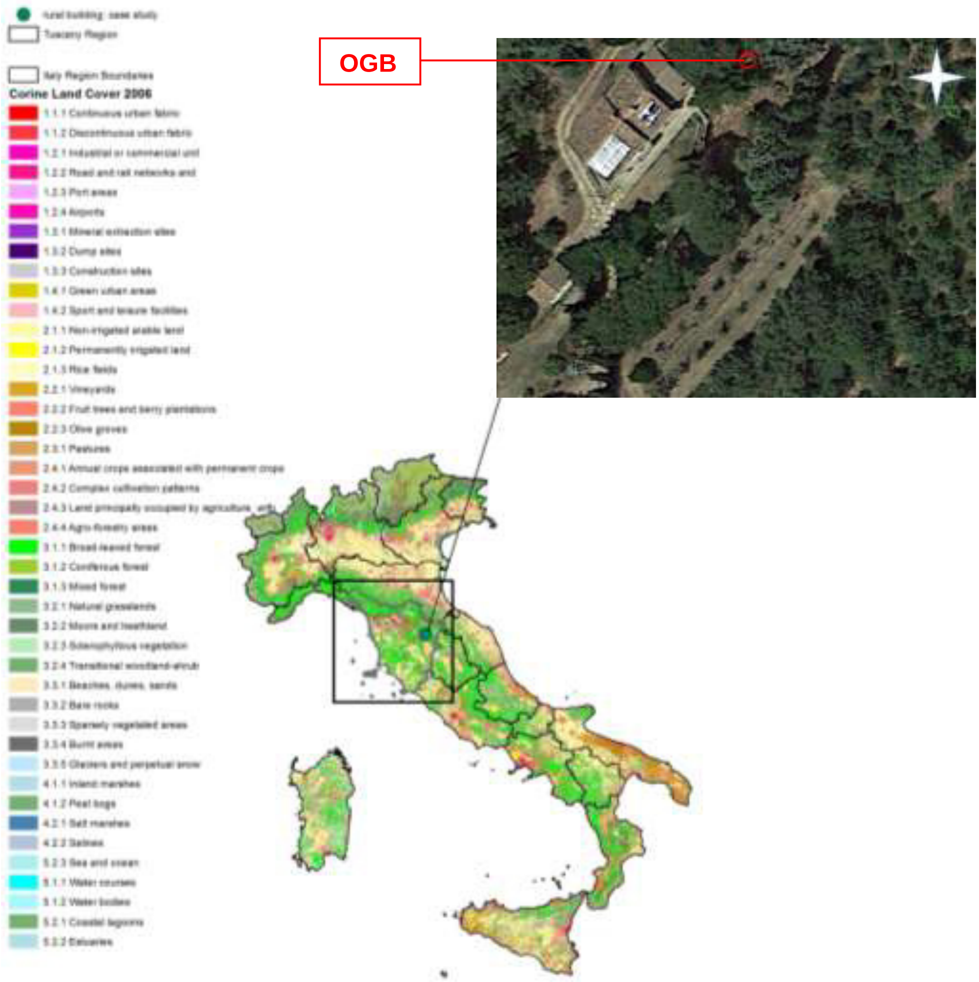

Fig. 3– OGB Sardini: installation site with view of the house and the garden family in Pieve San 179 Giovanni (Tuscany - Arezzo).

2. Material and methods

The methodology that has been followed has provided several logical steps with tree scenarios: A) ON-GRID (PV system and energy exchange with the grid); B) OFF-GRID (PV system and OGB with Lead-Acid Battery as storage system); C) OFF-GRID (PV system and OGB with Li-ion Battery as storage system). Starting from the real case described briefly above in section 1.3 (A scenario), two possibilities were envisaged alternative scenarios for energy storage (B and C scenarios), varying the positioning of the PV system (azimuth and tilt), its surface area and thus the its peak power. The logic is not to maximize the energy produced by the PV system (A), but to reduce the time shift, that is, the balance in time between production and use of energy. For the energy storage system in B scenario it is assumed the use of Valve-Regulated Lead-Acid Battery - type gel cells and for the case C of Lithium Ion battery, as they represent mature and accessible technologies. The real case study (A) allowed to monitor during the whole year 2013 the energy consumption of the building and the energy produced by the PV system. For the simulation of the energy produced by the PV system for the B and C scenarios, it used the open source tool "Simulare_11" available at link http://www.intellienergia.com/. Simulare is a techno-economic simulator for the design of solar photovoltaic systems designed by the Italian Spin-off Intellienergia. With "Simulare" was identified the optimal positioning of the panels (combinations of azimuth and tilt), setting the objective function the minimum gap between the trends in production and consumption. The optimal orientation resultant for the B and C scenarios is characterized by an azimuth of 0 ° and tilt of 90 °, which corresponds to the positioning of panels on a vertical surface (wall of the building facing south). The dimensioning of the batteries for the two simulated scenarios (B and C) is based on results from the monitoring of the actual case (A). These storage systems are designed for short-term energy storage can ensure energy self-sufficiency on a monthly basis. The benchmarks chosen for the the comparison of storage systems are: Depth of discharge, Energy and Power Density, Energy Efficiency and Life Cycle. These criteria are widely used in the literature to evaluate different batteries (Brinkhaus et al., 2011; Suha Yazici et al., 2013, Bielmann et al., 2011; Gray et al., 2011).

3. Results

Fig. 4 shows the trend of the radiation, monthly average plane of the modules for the area object of study.

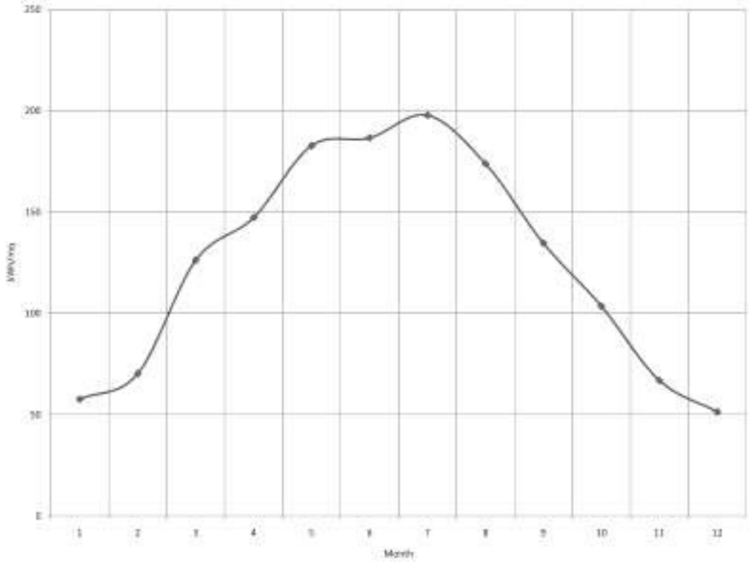

Fig. 4– Monthly Average Irradiance (kWh/month/m^2) geographic coordinate: Lat 43.529632° - Lon 11.794625

With the tool "Simulare_11" were simulated the monthly production for PV systems of cases B and C and compared with the case A. The results are summarized in Table 2 and represented in Fig. 5.

Tab. 2 – Consumption, level of production and energy in kWh for A,B,C scenarios on a monthly basis.

	Months	1	2	3	4	5	6	7	8	9	10	11	12	Total
	Consumption (instantaneous plus from the grid)	211,00	175,00	139,00	120,00	121,00	136,00	172,00	169,00	93,00	121,00	150,00	218,00	1825,00
A Scenario	Production	128,00	186,00	209,00	353,00	352,00	378,00	441,00	475,00	340,00	224,00	135,00	134,00	3355,00
	Energy surplus	-83,00	11,00	70,00	233,00	231,00	242,00	269,00	306,00	247,00	103,00	-15,00	-84,00	1712,00
B Scenario	Production	249,44	285,00	227,96	309,05	189,18	186,67	260,42	410,29	370,23	326,61	255,87	254,81	3325,53
	Energy surplus	38,44	110,00	88,96	189,05	68,18	50,67	88,42	241,29	277,23	205,61	105,87	36,81	1500,53
C Scenario	Production	226,31	258,57	206,82	280,39	171,63	169,36	236,27	372,25	335,90	296,32	232,15	231,18	3017,15
	Energy surplus	15,31	83,57	67,82	160,39	50,63	33,36	64,27	203,25	242,90	175,32	82,15	13,18	1192,15

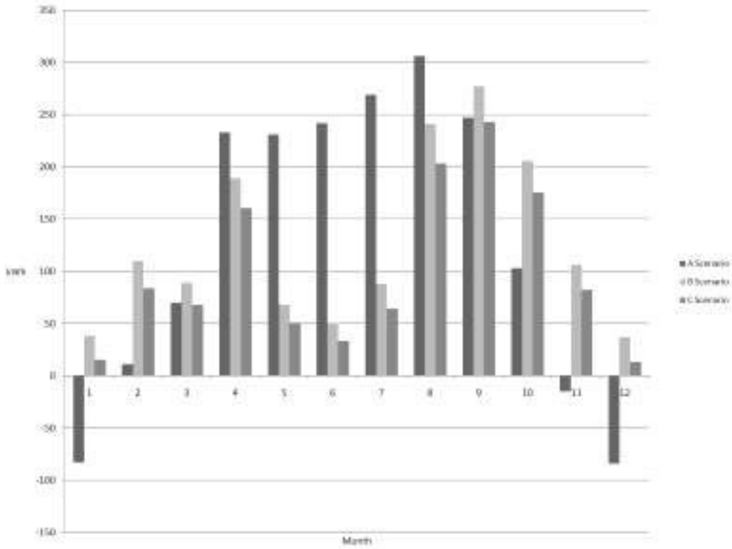

Fig. 5 – Comparison of surplus energy for A, B, C scenarios.

To better evaluate the efficiency of different storage systems, the analysis of production levels has been accompanied with a study of certain technical characteristics of VRLA and Li-ion battery. For comparison this characteristics, between different storage systems, were consulted numerous sources, in particular were examined Depth of Discharge (DOD), Energy and Power Density (P / E), Energy Efficiency, Cycle of Life. In terms of DOD Li-ion batteries take advantages over lead-acid (Linden and Reddy, 2002; Battery University BU-201, 2015; Battery University BU-808, 2015; The Electropaedia Battery performance characteristics, 2015); the P / E ratios typical of the two batteries are suitable for consumption requie (The Electropaedia Battery performance characteristics, 2015; Wikipedia, Ragone chart, 2015; Winter and Brodd, 2004; Barsali et al., 2011); the Li ion battery have a better Energy Efficency (Conte et al., 2015); in terms of Life Cycle the Li-ion battery have higher performance (Conte et al., 2015).

4. Discussion of results and Conclusions

4.1. Energy storage systems

As it regards the identification of the best energy storage system, in order to get results that can fully evaluate the sustainability of the choice it is necessary to compare the technical parameters used in the present work with economic and environmental parameters, such as the costs of the different systems as before by Thompson et al. (2009) and Chaurey et al. (2010).

4.2. Energy self-sufficiency

To achieve real self-sufficient energy system also with OGB it's necessary the design of the systems for optimize time shift and not for the maximization of energy production. The storage systems evaluated and compared in this work does not allow the use of the stored energy from one month to another, for this reason was necessary to oversize the PV system compared to the demand in order to have a monthly production higher to consumption. To make it interesting to the logic of energy self-sufficiency is needed:

- adopt solutions as the cases B and C and identify systems able to use the excess energy: see the water treatment system of the present in the OGB and summarized in Fig. 2, and still the possibility of using the electric energy for heating and / or conditioning (heat pumps);

- integrating the PV system with other renewable energy sources, characterized by complementary production deployments (eg hydroelectric energy, wind);
- adopt different storage systems with more energy autonomy like the fuel cell, currently with costs too many high to be applied to individual units;
- design of small scale smart grid characterized by individual units with different distributions of the energy requirements in order to match production and consumption.

With these assumptions in marginal rural areas, become actors of particular interest the small scale farms, with their restricted energy demand and the adoption of sustainable methods of production.

4.3. OGB to support the small scale food producers

The OGB is a compact system with small dimensions, affordable, suitable for contained energy demands. At the same time the OGB can be placed in existing buildings (as in the case study, in which the PV system is integrated in the coverage area) in order to meet different requirements in terms of energy, heat and water. The OGB is concrete and replicable solution for different rural contexts in order to obtain their winning energy planning. The results are modulated in different geographical contexts and demonstrate the feasibility and the strategic use of total off grid systems for individual units ensuring energy sovereignty of local communities. These systems should be designed in terms incorporated in the territory in order to realize the small-scale-smart-grid. These scenarios are interesting for small family farms that adopt sustainable models and methods of production with low environmental impact and low energy demand. In order to the our study area (Valnerina in Umbria region) can be assumed the technical feasibility for the OGB to cover the energy needs of a small slaughterhouse (mobile service to more than one farms, or permanent installed in a single production unit) for the slaughter of sheep. An italian regulations on the impact of the slaughtering sector states that energy demand for the average production of carcasses is around 400 kWh/t in terms of heat and power (Ministry of the Environment and Protection of Land and Sea of Italy 2007). In Fig. 6 are reported hypothetical levels of annual productivity in term of sheep carcasses for the three scenarios of energy production.

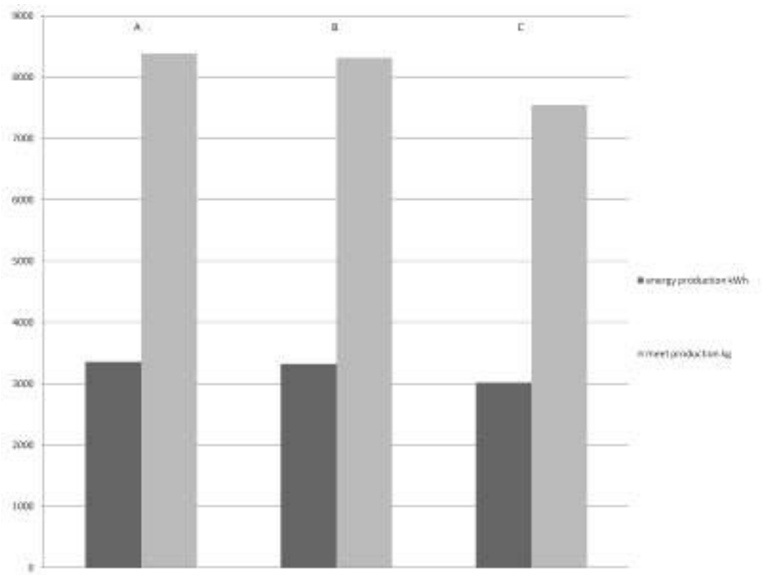

Fig. 6 – Comparison of surplus energy for A, B, C scenarios.

On the basis of the productivity of the OGB, only in terms of electricity in this study, is evident the strategic importance of its use to support small scale food producers in rural areas. The results are interesting for small family farms that adopt sustainable models and methods of production with low environmental impact and low energy demand to define the indications for their winning energy planning in a logico of off-grid farming.

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